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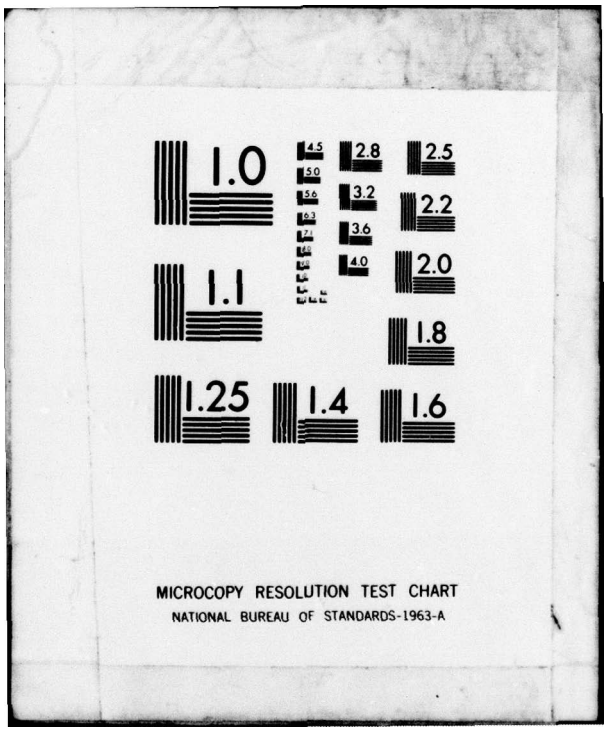
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WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

(14) WHOI-REF-49-48

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Reference No. 49-48

(6) MARINE METEOROLOGY.

Conducted during the Period

(15) N6onr-277

1 July - 30 September

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(9) Periodic Status Report No. 9, 1 Jul-30 Sep 49.

Submitted to the Office of Naval Research
Under Contract No. N6onr-277
Task Order No. II, NR-082-021
With Office of Naval Research

(11) Oct 49

APPROVED FOR DISTRIBUTION Alfred Redfield
Associate Director

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ABSTRACT

This report contains a summary of work carried out by the Woods Hole Oceanographic Institution with the support of the Office of Naval Research. Certain phases of this work are continuations of work formerly conducted under Contract ~~NObs-2083~~.

Dr. Joanne Starr Malkus, presented a paper on her studies of atmospheric convection to the glider meeting at Elmira at the beginning of July, 1949.

ABSTRACT

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The following is a copy of the task order originating this project.

Task order II - Constituting a part of Contract N6onr-277 with the Woods Hole Oceanographic Institution, and superseding dispatch advance notice of award effective April 1, 1947.

Section A - The contractor shall furnish the necessary personnel and facilities for, and conduct, in accordance with any instructions issued by the Scientific Office or his authorized representative, research in marine meteorology, such research to include:

(1) The determination of the flux of long wave radiation in the air;

(2) The study of the transport of heat and water by eddy diffusion;

(3) The study of ocean cloud formation;

(4) The establishment of a budget for the transport of water and heat in the Trades;

(5) The establishment of the temperature of the thin film of water actually in contact with the air;

(6) The determination of the weight and variations in time and locale of the sea salt present in a given volume of surface air;

(7) Exploration of the theory of a shift in the correlation of dry temperature and water vapor pressure in the lower atmosphere;

(8) Investigation of the turbulent eddies close to the sea surface; and

(9) Measurement of the transfer of heat from a body of water to a cooler air mass.

The personnel connected with this project are:

Dr. B. Haurwitz, (part-time)

Associate in Marine Meteorology and Supervisor,

Andrew F. Bunker

Research Associate in Meteorology,

Patricia A. Langwell

Research Associate in Meteorology,

Alfred H. Woodcock, (part-time)

Physical Oceanographer,

Kenneth G. McCasland

Senior Instrument Technician,

Donald Parsons

Electronics Technician,

Nellie Anderson, (part-time)

Computer,

Malkus, Dr. Joanne Starr (during July and August)

Illinois Institute of Technology.

Lt. Charles L. Hosler, Jr., U.S.N.R. and Lt. John Sherrod, U.S.N.R. each spent two weeks at the Institution as their tour of active duty and worked on various parts of the project. Lt. Comdr. Franklin G. Mullon, U. S. N.R. visited the project as ONR representative.

Other visitors included: Mr. R. C. Jacobsen, Asst. Controler

Meteorological Service of Canada, Dr. E. W. Hewson and some of his collaborators from the Round Hill Station of M.I.T., and Mr. F. Graham Millar, Meteorological Service of Canada.

Program

(1) The study of the transport of heat and water vapor by eddy diffusion.

The vertical vane described in Status Reports No. 7 and No. 8 has been tested and used on several days with varying degrees of thermal stability. From the data obtained heat flows have been computed, and a study of the relation between temperature fluctuations and vertical velocities is being made. A technical report is now in preparation which describes the work and discusses the relation between the transport of heat and the temperature gradient.

It was found that the computation of heat flows from the individual traces of temperature, wind velocities, and angle of inclination were extremely laborious and time consuming. To remedy this an electronic computer is being constructed that will multiply the three terms. The product can be fed into an integrator, which will give the total heat flow for any length of time desired. The computer-integrator, together with a newly designed vane, is being made portable so that values can be obtained at scattered points on beaches, islands, or inland.

A short article is being written describing observations recorded by the vertical vane during the passage of the cold outflow of air descending from the center of a nearby thunderstorm. An updraft of air ahead of the cold air and other significant changes in the air turbulence are shown by the records.

Another use of the wind inclination vane is the comparison of the accelerations imparted to an airplane by the turbulence of the air and the vertical velocities determined from the record of the vane at the same height. This comparison permits one to establish the mean value of the short-period vertical velocities at all altitudes to which a plane can fly. More data must be collected before the relationship is determined with sufficient accuracy.

(2) The determination of the weight and variations in time and locale of the sea salt present in a given volume of surface air.

No work has been done on this problem during the period.

(3) The study of turbulence patterns in the atmosphere and their relation to temperature variations along the horizontal.

a) The mathematical study discussed in Periodic Status Report No. 8 of this project has been continued. An attempt has been made to show the importance of variation of each of the measurable quantities involved in the equations. It is anticipated that the paper will be written during the next few months.

b) During the progress of the Thunderstorm Project, numerous papers describing the cellular nature of thunderstorms have been published. They describe the life cycle of a cell in three stages:

(1) a growing cell, in which all vertical motions within the cloud are upward,

(2) a mature cell, with some up- and some down-drafts, and rain falling from the cloud,

(3) a dissipating cloud, with no up-drafts.

An attempt is being made to derive the criteria whereby a cell will pass from stage 1 to 2. This problem is approached by testing for points of weakness in a cloud, from which rain would fall first.

The total vertical force within the cloud is $\rho_1 \frac{dw}{dt}$, where ρ_1 is the density of the cloud, including water droplets, and w is the vertical velocity. The downward force within the cloud is $\rho_2 g$, where ρ_2 is the mass/volume of raindrops, and g is gravity. The mass of raindrops increases with time, and shows a variation with height which is negligible for small z, (near the base of the cloud) and above the freezing level, but different from zero for the intervening height interval.

When $(\rho_1 \frac{dw}{dt} - \rho_2 g > 0)$, the net force is upward, and the cloud is in stage one. When the net force is negative, down-drafts exist within the cloud.

The problem may be considered as two-dimensional, with the wind field

$$U = U_o + hz,$$

where z is vertical upwards and z = 0 at the base of the cloud,

and x is in the direction of the wind, with x = 0 at the windward edge of the base of the cloud, and the entire system moving with the speed U_o. Further,

$$\frac{dw}{dt} = \frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + w \frac{\partial w}{\partial z},$$

where u and w are the horizontal and vertical velocities of the cloud-air respectively. According to Malkus, (Effects of Wind Shear on Some Aspects of Convection, Transactions A.G.U., v. 30, pp. 19-25, 1949), u may be calculated as a function of height if h, the wind shear, and the rate of entrainment are known.

If it is assumed that

$$w = A(z) \sin \gamma t \sin \alpha x,$$

where A (z) depends on the instability of the environment $\gamma = \pi/t_1$, where t_1 is the period of pulsations of growth of the cloud, and $\alpha = \pi/x_1$ where x_1 is the width of the base of the cloud. The amplitude increases with height to a maximum and then decreases to zero. The term $\sin \alpha x$ indicates the jet-like shape of the vertical motion, and $\sin \gamma t$ is a measure of the strength of the jet.

Substituting these expressions into the inequality,

$$\gamma A \cos \gamma t \sin \alpha x + \alpha A u(z) \sin \gamma t \cos \alpha x + \frac{dA}{dz} A \sin^2 \gamma t \sin^2 \alpha x \geq \varepsilon \frac{\rho_2 (z,t)}{\rho_1 (z)}$$

The right hand term in non-negative. Initially the first term is most important, but as t approaches $\pi/2t_1$, $\cos \gamma t \simeq 0$, and $\sin \gamma t \simeq 1$. The relationship is then

$$\alpha A\, u(z) \cos \alpha x + \frac{dA}{dz} A \sin^2 \alpha x \gtrless g \frac{\rho_2 (z,t)}{\rho_1 (z)}$$

Rain can fall when $g \rho_2/\rho_1$ is larger than the left-hand side of this inequality. It may be assumed that the growth of the cloud extends above the height where $\frac{dA}{dz} = 0$. Since $u(z)$ has the same sign as the wind shear, the left-hand side of the inequality will be negative for positive h when $\cos \alpha x < 0$, and for negative h when $\cos \alpha x > 0$. For $h = 0$, $u(z) = 0$, and the optimum regions for initial rainfall are those where $\sin^2 \alpha x$ is minimal, at the edges of the cloud. It should be noted that this treatment requires, not an initial down-draft, but a deceleration of w.

Through the kindness of Mr. Merrill Bernard, U.S.W.B., Washington, D.C., the data of the Thunderstorm Project have been made temporarily accessible. They contain a great deal of information by which this theory may be checked, and the investigation of this phase of the work is continued.

c) A study of convection set up by the islands in the Woods Hole region was made during the period. On many days during the summer, streets of cumulus clouds are observed streaming out downwind from the islands of Nantucket, Martha's Vineyard, and frequently from the even smaller Elizabeth Islands. The problem is to predict the conditions of stability, wind, insolation, etc., under which the phenomenon will occur, and the spacing, degree of development, and character of the clouds or thermals as a function of the other parameters.

The main factors initiating the development of these periodic updrafts have been assumed to be 1) the barrier effect of the islands, whose height above sea level reaches 150 ft. in places; 2) the difference in frictional drag on the wind between sea and island, giving rise to convergence and updrafts on the windward shore, divergence and downdrafts on the leeward shore; 3) the heating of the air by the island. It is assumed that in most cases of such cloud streets, the heating effect is predominant.

The problem was set up as a perturbation problem in two dimensions (the vertical dimension, z, and x, the direction of the horizontal wind). The fluid considered is compressible, with a constant lapse-rate of temperature, and one of the frictional terms in the Navier-Stokes equations of motion is retained. The basic motion, U, varies with elevation.

A heat source is considered which decreases exponentially

with elevation, and exhibits a single pulse in the x-direction, giving rise to an inhomogeneous term in the differential equation. Analysis of the preliminary results shows that the amplitude of the lee waves is directly related to the heating and the width of the island, and inversely related to the wind velocity and the square-root of the stability. A preliminary examination of orders of magnitude indicates that on a summer day for which the stability is small, normal heating is probably sufficient to give updraft amplitudes up to 3 mps, with wave lengths of the order of 1/2 to 5 km.

During the summer of 1949 observational case studies were made of convection in the Woods Hole area, which are described in detail in a Technical Report to be issued by the project during the fall of 1949. In these studies, an aircraft was used which made accelerometer records of turbulence, dry and wet bulb temperature soundings and still photographs. Ground observations included time-lapse motion pictures, pilot balloon ascents, pyrheliometer, and water temperature observations.

In addition to providing information regarding the role of the islands in cumulus cloud production, these observational case studies were used to test the results of earlier theories[1] regarding the effects of wind shear on convection. It was found that the hypothesis of the partial conservation of horizontal momentum by an updraft ascending through an environment where the wind varied with height checked excellently. Most notable was a case where the wind changed sharply in direction with height, and the cumulus clouds were found moving in a direction quite different from that of the ambient wind. The predicted asymmetry between area of active turbulence and that of visible cloud also checked.

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[1] Presented in a paper by Joanne Starr Malkus in the Transactions of the American Geophysical Union, February, 1949.